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Isotope studies and chemical investigations of Tattapani hot springs in Kotli (Kashmir, NE Pakistan): Implications on reservoir origin and temperature

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Abstract

The present study is focused on the isotopic signatures and geochemical analyses of the geothermal field of Tattapani area in Kotli District of Kashmir (Pakistan) to understand the origin, subsurface history and reservoir temperature. The study area encompasses of complex overlapping thrust tectonics due to its close affinity to the suture zones of relatively younger ongoing collision between Indian and Eurasian plates (<55Ma). The area is located on the apex of active Balakot-Bagh Fault (Kashmir earthquake, 2005), besides other regional thrust faults in the surroundings including Riasi Thrust, Punjal Thrust, Main Boundary Thrust and the Himalaya Frontal Thrust respectively. Field observations revealed that the water discharge of the springs varies from 4.3 to 11.8 liters per second with the surface temperature from 59.2 to 60.7°C. Samples collected are analyzed for various isotopes (^{18}O, ^{2}H & ^{3}H of water) and water chemistry, which synthesized that the thermal waters are slightly acidic and have low dissolved contents. Sodium and bicarbonate are dominating ions. δ^{18}O and δ^{2}H of all the sampled geothermal manifestations were found to be –6.54 to –6.19‰ and –41 to –37‰ respectively. Source of recharge is meteoric water (rains at higher altitude), whereas thermal waters are of immature nature with a significant component of fresh water mixing and circulation time of about 40 years. On the basis of K–Mg and Na–K–Mg thermometers, the average reservoir temperature is 140°C. In addition, geothermometer based on dissolved silica showed average reservoir temperature about 105°C.

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Keywords: Hot springs, Isotope study, Hydrogeochemistry, Reservoir temperture, Pakistan.

1. Introduction

Geothermal fields are widely been studied to understand the mechanism of hot springs, prospects for economic utilization and domestic use[1,2,3]. Tectonic framework and related magmatism plays a significant role in the origin of geothermal resources. Geodynamic evolution of the Pakistan supports the presence of exploitable sources of

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geothermal energy. This is further concreted by the presence of numerous alteration zones, fumaroles, hot springs and imprints of quaternary volcanism[4]. Geothermal activity in the northern areas of Pakistan is related to the ongoing collision of the Indian Plate with the Eurasian Plate, whereby resulted in the origination of regional thrust system (i.e., Main Mantle Thrust, Main Karakoram Thrust and Main Boundary Thrust)[5]. Besides this, subduction of the Arabian Plate beneath the Indian plate in the South-West resulted in the emergence of the Chaghai volcanic arc where quaternary volcanism is associated with recent tectonism[6].

The study area (i.e., Tattapani hot springs) occurs on the gravely bank of Ponch River at Tattapani town, near Kotli, Kashmir (NE Pakistan). Field investigations revealed magmatic intrusions in the exposed carbonate successions, which may lead to the understanding of near surface magmatism. Besides this, regional active tectonism (Balakot-Bagh Fault) caused recent activities (i.e., Kashmir earthquake of 7.8M) may have provided pathways for the hot solutions. Isotopic signatures of the studied hot springs provided evidence towards the understanding of possible origin and age of these thermal waters. In addition, geochemical analysis for major ions revealed fair assessment about chemical nature and sub-surface reservoir temperatures of thermal waters.

2. Geological Settings

The study area is part of the Sub-Himalayas, where folded to imbricated Pre-Cambrian to Tertiary rock sequence is exposed. Hazara Kashmir syntaxis in the region is characterized by syntaxial band, where a series of overlapping thrusts emerged. These include: Punjal Thrust, Main Boundary Thrust and the Himalaya Frontal Thrust. The Murree Thrust corresponds to the Main Boundary Thrust in India[7,8]. The study area is a part of Kashmir foreland and thrust belt, which lies along the eastern limb of the Hazara Kashmir Syntaxis in sub Himalayas. The whole study area is comprised of sedimentary rocks ranging in age from Pre–Cambrian to recent. The Pre–Cambrian Muzaffarabad formation overlies the Cenozoic rocks due to up lifting and erosions. Sill and dykes of basic composition have been observed in the many part of the Tattapani area[9]. Tattapani hot springs are located on the northern tip of Tattapani anticline which is bounded by a reverse fault on its southwest side, southwest of which the Murree Formation (Early Miocene) is juxtaposed against the Dhok Pathan Formation (Late Miocene) of the Siwalik Group on the Riasi thrust[10] (Fig. 1).

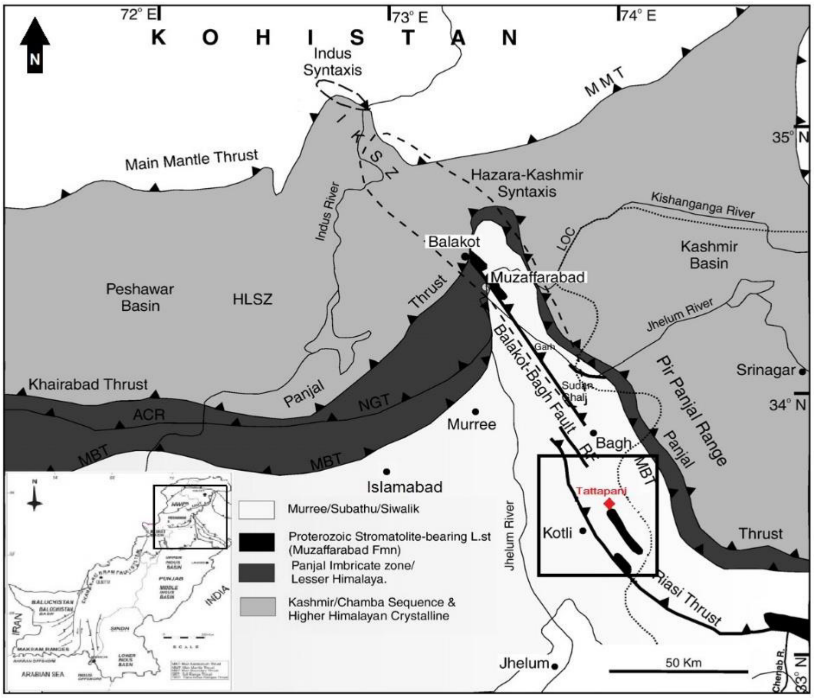

Fig. 1. Tectonic Map of North Pakistan showing location of Study area along with major Tectonic Thrusts[8]; RF=Rawalkot Fault; IKSZ=Indus Kohistan Seismic Zone; HLSZ =Hazara Lower Seismic Zone; NGT=Nathia Gali Thrust, MBT=Main Boundary

3. Material and Methods

For chemical and isotopes analyses, water samples were individually collected in high quality Polyethylene PET plastic bottles i.e., 200 ml each for cations, anions, silica, and isotopes (^{2}H, ^{18}O), while 1L for analysis of ^{3}H. Samples collected for cations analysis, were acidified with conc. HNO_3 to avoid precipitation upon storage. Samples collected for SiO_2 were diluted (1:1) with deionized water to prevent silica polymerization. Samples were filtered with filter paper (0.45µm) where necessary. Chemical analyses were carried out using: atomic absorption spectrophotometry for Na, K, Ca and Mg; UV–visible spectrophotometry for Si; and titrimetry for HCO_3, SO_4 and Cl[11]. The δ^{18}O value of the water was measured by mass spectrometer using the CO_2 equilibration method[12]. δ^{18}O values of water were analyzed relative to V–SMOW with a standard error of ±0.1‰. The tritium content of the samples were determined by liquid scintillation counting after electrolytic enrichment of the water samples with a standard error of ±1 TU[13].

4. Results and Discussions

4.1 Chemical and Isotopic Origin of Tattapani Hot springs

Chemical parameters of all the thermal springs plotted in Schoeller diagram (Fig. 2) indicate that the origin is same for the whole group. Isotopic data can differentiate between the three possible types of origin of thermal water i.e. magmatic, oceanic and meteoric[14]. Ranges of δ^{18}O and δ^2H of all the sampled geothermal manifestations are –6.54 to –6.19‰ and –41 to –37‰ respectively. These data do not show the presence of any magmatic water which generally has δ^{18}O: +6 to +9‰ and δ^2H: –40 to –80‰[15]. The important feature of the fluids emerging from thermal manifestations is their low salt contents. The Cl content of Tattapani thermal waters varies from 91 to 144 ppm. Normally the oceans have δ^{18}O and δ^2H about 0‰ (VSMOW), the salinity from 33500 to 37600 ppm and chloride about 19300 ppm[16]. The possibility of oceanic origin is ruled out due the absence of highly enriched δ^{18}O, δ^2H, EC and Cl values. So the origin of thermal waters is apparently meteoric. All the data points lie below and close to LMWL in δ^{18}O vs. δ^2H diagram (Fig. 3). Their δ^{18}O and δ^2H are more depleted than the river water, which implies that they are recharged at higher altitude further in the North. Tritium of thermal springs varies from 7 to 9 TU, while that of river water and open well is 16 TU and 18 TU. The tritium data show that all these waters were recharged during and after the start of nuclear weapon testing in 1952[16], which means residence time could be around 40 years.

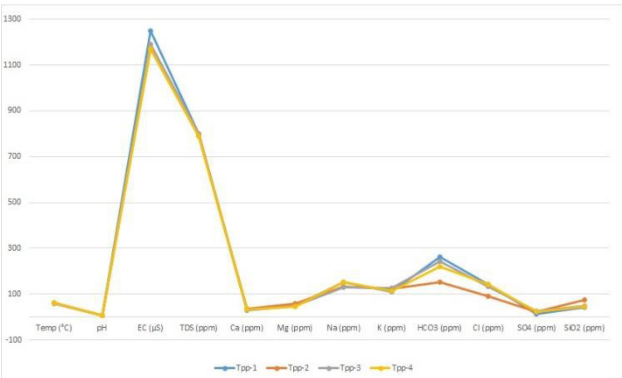

Fig. 3. Schoeller Diagram for Tattapani thermal springs

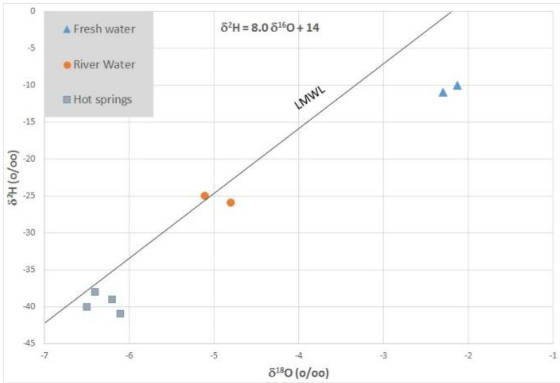

Fig. 2. δ^{18}O vs. δ^2H plot for sample collected from Tattapani area.

4.2 Hydro-geochemical Nature of Tattapani Hot springs

Thermal waters of Tattapani have low dissolved salts as indicated by their EC values ranging from 1170 to 1250 µS/cm. EC and pH (6.62 – 6.65) values of all the thermal springs are close to each other. EC and pH values of a cold spring and tap water samples from a nearby area are 510, 1020 µS/cm and 7.45, 7.44 respectively. River water samples have quite low EC and pH values. i.e. 230 µS/cm and 7.6 respectively. Triangular diagrams of cations and anions (Fig. 4) indicate that Na and HCO_3 are the dominant ions in all the samples. Hence these thermal waters are of Na–HCO_3 type.

4.3 Reservoir Temperatures of Tattapani Hot springs

Chemical geothermometers like Na–K, K–Mg, Na–K–Ca, Na–K–Ca–Mg and quartz geothermometer are used to estimate reservoir temperatures using following equations:

$$T_{quartz}\,(°C) = [1309/\{5.19 - log\,(SiO_2)\}] - 273.15^{17} \quad (1)$$

$$T_{Na-K}\,(°C) = [933/\{0.993 + log\,(Na/K)\}] - 273.15^{18} \quad (2)$$

$$T_{K-Mg}\,(°C) = [4410/\{14.0 - log\,(K^2/Mg)\}] - 273.15^{19} \quad (3)$$

$$T_{Na-K-Ca}(°C) = [1647/\{log(Na/K) + \beta log(Ca^{0.5}/Na) + 2.24\}] - 273.15^{20} \quad (4)$$

$$T_{Na-K-Ca-Mg}(°C) = [16000/\{3log(Na/K) + \beta log(Ca/Na2) - log(Mg/Na2) + 44.67\}] - 273.15^{21} \quad (5)$$

SiO_2 geothermometer gave low temperatures (96–120°C) while K–Mg and Na–K–Ca–Mg thermometers yielded similar temperatures (106–130°C), Na–K–Ca gave higher temperature estimates (190–205°C). Na–K geothermometer yielded too much high results[21], so they were ignored.

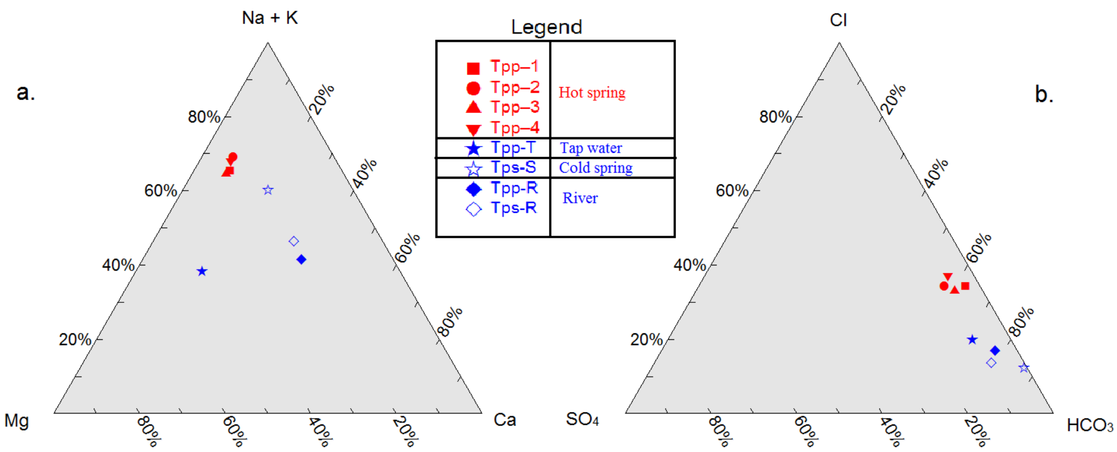

Fig. 4. Ternary Plot of major ions concentration of water samples of Tattapani area. (a) Major Cations; (b) Major Anions.

5. Conclusion

Tattapani hot springs are of meteoric origin and are sodium bicarbonate type. Geothermal water is young and significant component of fresh water is mixing possibly due to the infiltration of nearby river water. Average reservoir temperatures given by cation and quartz geothermometers are 140°C and 100°C respectively. Based of reservoir temperatures it could be concluded that Tattapani geothermal system is low enthalpy system and is suitable for domestic use.

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References

1. Lund JW, Freeston DH. World-wide direct uses of geothermal energy 2000. *Geothermics* 2001; *30*.1:29-68.
2. Lund JW, Freeston DH, Boyd TL. Direct application of geothermal energy: 2005 worldwide review. *Geothermics* 2005; *34*.6:691-727.
3. Fridleifsson IB, Freeston DH. Geothermal energy research and development. *Geothermics* 1994; *23*.2:175-214.

4. Shuja TA. Geothermal areas in Pakistan. *Geothermics* 1986; 15.5:719-723.
5. *Bakht MS.* An overview of geothermal resources of Pakistan.*Proceedings World Geothermal Congress 2000.*
6. Zaigham NA, Zeeshan AN, Noushaba H. Review of geothermal energy resources in Pakistan. *Renewable and Sustainable Energy Reviews* 2009; 13.1:223-232.
7. Thakur VC, Jayangondaperumal R, Malik AM. Redefining Medlicott–Wadia's main boundary fault from Jhelum to Yamuna: An active fault strand of the main boundary thrust in northwest Himalaya. *Tectonophysics* 2010; 489.1:29-42.
8. Hussain A, Robert S Y. Geological setting of the 8 October 2005 Kashmir earthquake. *Journal of Seismology* 2009; 13.3:315-325.
9. Ashraf M, Chaudhry MN, Qureshi KA. Stratigraphy of Kotli area of Azad Kashmir and its correlation with standard type areas of Pakistan. *Kashmir Jour Geol* 1983; 1.1:19-30.
10. Hussain SH, Haq I, Hussain A. Geological map of the Khuiratta area, District Kotli, AJK: Geol. Survey of Pakistan Geological Map Series v 2004, VI, no. 27, Sheet No. 43 K/3, 1:50,000.
11. American Public Health Association. APHA. *Standard methods for the examination of water and wastewater.* 21th ed. Washington: APHA; 2005.
12. Epstein S, Toshiko M. Variation of O 18 content of waters from natural sources. *Geochimica et cosmochimica acta* 1953; 4.5:213-224.
13. Hussain SD, Asghar G. *Program for TI programmable 59 calculator for calculation of ^{3}H concentration of water samples*. Pakistan Inst. of Nuclear Science and Technology, Rawalpindi: Radiation and Isotope Applications Div; 1982.
14. Ahmad M, Waheed A, Niaz A, Tasneem MA, Rafiq M, Latif Z. Assessment of reservoir temperatures of thermal springs of the northern areas of Pakistan by chemical and isotope geothermometry. *Geothermics* 2002; 31.5:613-631.
15. Giggenbach WF. Isotopic shift in waters from geothermal and volcanic systems along convergent plate boundaries ad their origin. *Earth and Planetary Science Letters* 1992; 113:495-510.
16. Clark ID, Fritz P. *Environmental Isotopes in Hydrogeology*. Boca Raton, New York: Lewis Publishers; 1997.
17. Fournier RO. Chemical geothermometers and mixing models for geothermal systems. *Geothermics* 1977; 5.1:41-50.
18. Arnorsson S. Chemical equilibria in Icelandic geothermal systems—implications for chemical geothermometry investigations. *Geothermics* 1983; 12.2:119-128.
19. Giggenbach WF. Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators. *Geochimica et cosmochimica acta* 1988; 52.12:2749-2765.
20. Fournier RO, Truesdell AH. An empirical Na-K-Ca geothermometer for natural waters. *Geochimica et Cosmochimica Acta* 1973; 37.5:1255-1275.
21. Ahmad M, Sheikh MR, Akram W, Tasneem MA, Iqbal N, Latif Z. *Investigation of geothermal fields in Himalayan range in pakistan using isotope and chemical techniques*. Pakistan Inst. of Nuclear Science and Technology, Islamabad (Pakistan): Isotope Application Div; 2007.